2019

Perceptions of climate change and occupational heat stress risks and adaptation strategies of mining workers in Ghana

Victor Fannam Nunfam
Edith Cowan University

Jacques Oosthuizen
Edith Cowan University

Kwadwo Adusei-Asante
Edith Cowan University

Eddie van Etten
Edith Cowan University

Kwasi Frimpong
Edith Cowan University

10.1016/j.scitotenv.2018.11.480
This is an Author's Accepted Manuscript of: Nunfam, V. F., Oosthuizen, J., Adusei-Asante, K., Van Etten, E. J., & Frimpong, K. (2019). Perceptions of climate change and occupational heat stress risks and adaptation strategies of mining workers in Ghana. *Science of the Total Environment*, *657*, 365-378.
Available here.

Perceptions of climate change and occupational heat stress risks and adaptation strategies of mining workers in Ghana

Abstract

Heavy physical workload for long hours coupled with increasing workplace heat exposure due to rising temperatures stemming from climate change, especially where there are inadequate prevention and control policies, adversely affect workers' health and safety, productive capacity and social well-being. However, variations in workers' concerns and awareness of occupational heat stress and climate change risks impede the effectiveness of heat stress management. A mixed method approach was used to assess climate change perceptions and occupational heat stress risks and adaptation strategies of Ghanaian mining workers. Questionnaires and focus group discussions were used to collect data from 320 respondents. Quantitative and qualitative approaches were used for data analysis. Workers' climate change risk perception, as confirmed by trends in climate data, was reasonable, but concerns about climate change effects and workplace heat exposure risks varied significantly across types of mining activity ($p < 0.001$). Workers experienced heat-related morbidities, but the variation in heat-related morbidity experiences across the type of mining activity was not significant. However, the type of heat-related morbidities experienced by workers differed across the type of mining activity ($p < 0.001$). Workers' awareness of occupational heat stress prevention and control was adequate. The disparities in workers' awareness and use of the prevention and control measures significantly differed across the type of mining activity ($p < 0.001$). Occupational heat stress prevention activities should focus on workers, and a concerted effort must be made to promote workers' adaptive capacity and inform policy decisions.

Keywords: adaptation measures, climate change risk, Ghana, heat stress experience, mining workers, perception

1. Introduction

Key components of the global development agenda to improve people's lives and livelihoods, as envisioned in the 2030 Sustainable Development Goals (SDGs), are to ensure healthy lives and promote well-being (SDGs 3), guarantee decent jobs and economic growth (SDGs 8), and combat increasing temperature and other climate change impacts (SDGs 13) (Leal Filho et al., 2018; United Nations (UN), 2015). These SDGs are reasonably informed by climate change and heat waves, which negatively impact on workers' health and safety, productivity, and social well-being due to heat exposure (Kjellstrom et al., 2016a; 2016b).

Evidence of global climate change risks due to increased human-induced Greenhouse Gas (GHG) emissions includes increasing temperature and humidity, more erratic precipitation, and rising sea levels over medium to long timeframes. It also includes more extreme weather events (e.g., storms, prolonged drought, floods and heatwaves) (United Nation Framework Convention on Climate Change [UNFCCC], 2010). Intergovernmental Panel on Climate Change (IPCC) reports have shown that global CO_2 concentrations have increased around 290 ppm since 1880 to 405 ppm in 2016 and 406.55 ppm as of August 2018 (IPCC, 2014b; Scripps Institution of Oceanography, 2018). Without effective climate change mitigation, CO_2 concentrations are likely to increase to somewhere between 540 - 1300 ppm in the period 2030 to 2100. The global mean temperature increase since the 1850s (currently 0.6 ± 0.2 ºC) is estimated to increase by between 1.4 ºC and 5.8 ºC in 2100 (IPCC, 2014c). Although continental precipitation has increased by 5 - 10% in the Northern Hemisphere over recent decades, it has decreased in other regions (e.g., West and North Africa, and parts of the Mediterranean). Global mean annual precipitation is estimated to increase in the 21st Century but with regional-scale variations projected at 5 - 20%. Global mean sea levels have risen since 1890. Sea levels are currently rising at a rate of about 3.2 mm per year, and may increase by up to 2 m by 2100 (NASA, 2018a; 2018b).

Climate change data in Africa have shown an increase in temperature (~0.7 °C) over the continent, a decrease in rainfall in parts of the Sahel region, and an increase in rainfall in East and Central Africa during the 20th Century (IPCC, 2001). During the 21st Century, the temperature is expected to increase in Africa faster than the global average increase, whereas mean annual precipitation is projected to decrease in outer regions (Mediterranean, Northern, and Southern Africa), increase in Central and Eastern Africa, and vary in West Africa (IPCC, 2014a).

Ghana's mean temperature increased by 1 ºC at an average rate (0.21 ºC) per decade (1960-2000) and is projected to increase by between 1.0 ºC-3.0 ºC in 2060 and 1.5 ºC-5.2 ºC in the 2090s (Government of Ghana[GoG], 2013, 2015). Trend and variability analysis have showed that rainfall was unpredictable but reduced in amount in recent decades. Sea levels rose by 2.1 mm per year over the period (1960-2000) and are projected to increase by 5.8 cm and 16.5 cm in 2020 and 2050 respectively (GoG, 2013, 2015).

The predicted rise and intensity of temperature and humidity levels in tropical developing countries like Ghana driven by climate change aggravate the impacts of excessive work-related heat exposure on varied workplace environments (e.g. indoor/outdoor) and industries including the mining sector. Thus, the study of mining workers as both beneficiaries of the socioeconomic development of mining and victims of climate change-related occupational heat stress risks due to working outdoors for long hours (as compared to other industries) is deemed worthwhile. The mining sector plays a key role in the Ghanaian economy involving direct foreign and local investments, foreign exchange earnings, employment, income and revenue generation (Ghana Statistical Service (GSS), 2015; McMahon and Moreira, 2014).

The interrelated concerns of industries including mining operations and climate change-related heat exposure can have substantial adverse effects on workers' occupational health and safety, productive capacity, and productivity of industries including mining companies. For instance, in the US, 423 cases of death were recorded among all workers including 68 crop production workers because of heat exposure from 1992 to 2006 (CDC, 2008). Also, an aggregate of 20 cases of heat-related morbidity and mortality that occurred among workers were reported by the Occupational Safety and Health Administration (OSHA) during an analysis of federal cases of heat exposure in 2012-2013 (Arbury et al., 2014). In South Korea, a study of workers' compensation data (2010-2014) revealed 47 incidents of illness among outdoor workers due to environmental-related heat exposure (Park et al., 2017). Furthermore, nonattendance and decreased work execution because of heat resulted in an economic loss of US$655 per individual and an overall financial burden of US$6.2 billion in Australia (Dunne et al., 2013). Worldwide modelling of labour efficiency losses predicts a reduction in work capacity in the most humid month of the year by 37% and 20% based on climate change projections RCP8.5 and RCP 4.5, respectively (Zander et al., 2015).

Despite predictions of increased heat-related impacts on workers in a warming climate, the relationship between increasing temperatures and heat stress perceptions by workers are not well understood (Zander et al., 2017). Small-Scale Mining (SSM) and Large-Scale Mining (LSM) activities (e.g., surface and underground mines) in hot and humid weather conditions without adequate mitigation, coping, adaptation and social protection increases mining workers risk to heat-related morbidities which result in absenteeism, loss of productive capacity, slow work pace, and poor social well-being (Kjellstrom et al., 2016b; Nunfam et al., 2018). SSM operations are informal mining practices by individuals, groups or cooperations with inadequate technology, whereas LSM operations are carried out by multinational companies with advanced technology. There may be differences in the impact of occupational heat stress between these two types of mining.

Climate change-related occupational heat stress management strategies are available, but its effective management depends on workers' and supervisors' awareness of heat stress impacts as well as prevention and control strategies. As such, multiple studies have explored perceptions and experiences of heat exposure and climate change impacts, and adaptation strategies of worker cohorts (Balakrishnan et al., 2010; Flocks et al., 2013; Xiang et al., 2015, 2016). However, there generally appears to be less concern and inadequate awareness of occupational heat stress risks of working in hot settings among workers despite the growing anxiety among researchers about the impacts of excessive heat exposure on workers (Crowe et al., 2009). Similar studies also confirmed inconsistencies with concerns and knowledge of heat exposure risks, and adaptation strategies among workers, supervisors, and other stakeholders (Xiang et al., 2015). Unlike the construction, manufacturing, and agricultural industries (Balakrishnan et al., 2010; Jacklitsch, 2017; Xiang et al., 2016), there is inadequate research into climate change perceptions and occupational heat stress risks and adaptation strategies among SSM and LSM workers in Africa. Therefore, an investigation into the trend and variability of climate change, climate change perceptions and occupational heat stress risks, and adaptation strategies of mining workers in Ghana is appropriate. This study also assessed the difference in demographic and work characteristics, climate change risks perception, occupational heat stress risks, and adaptation strategies between the two types of mining workers (SSM and LSM).

2. Material and methods

2.1 Philosophical perspective and study design

Based on the pragmatist philosophical perspective, this study employed the concurrent mixed methods and descriptive cross-sectional survey approaches to provide an assessment of the research problem (Creswell, 2013; Creswell and Clark, 2017). The study combined quantitative and qualitative strategies to seek complementary and corroborative assessment, description and understanding of mining workers' climate change perception, occupational heat stress risks, and adaptation strategies at a point in time in Ghana as a case study (Creswell, 2013; Mertens, 2015).

2.2 Study setting, population, sampling procedure and sample size

Ghana is situated in the West African sub-region. Ghana was chosen for the study because it has a tropical climate couple with being a hub of mining activities susceptible to the risks and impacts of heat exposure. Mining activities in Ghana are characterised by inadequate technology, low adaptive capacity and the high intensity of mining workers, particularly in the informal sector. There is also an absence of studies on the impact of climate change and occupational heat stress and adaptation in Ghana's large mining industry (GoG, 2015; GSS, 2013). This study was conducted among mining workers at five mining sites within the Western Region of Ghana (Fig 1). In Ghana, mining is commonly operated by accredited Artisanal and Small-Scale Mining (ASSM) and LSM operators, which are mostly multinational mining companies.

The study population is over one million mining workers and consisted of approximately a million people directly engaged in ASSM (McQuilken and Hilson, 2016), and some 9,939 employees engaged by the 13 LSM companies operating in the country as of 2015 (as compared to 12,382 in 2014; Ghana Chamber of Mines (GCM), 2015). Purposive sampling was employed to select eight out of the estimated over 177 registered ASSM companies, and five out the 13 LSM companies who willingly participated in the study with informed consent (Bernard, 2017). Simple random sampling was then employed in selecting 320 respondents consisting of individual mining workers of SSM companies (161) and LSM companies (159) who expressed their willingness to participate in the study based on informed consent.

….Insert Fig 1. A map showing five mining sites located in the Western Region of Ghana

Data sources and collection methods

The study relied on both primary and secondary data. Questionnaires and Focus Group Discussions (FGD) guide were employed to elicit self-reported perception and experiences of climate change and occupational heat stress risks and adaptation strategies of mining workers. The questionnaire was guided by the validated instruments adopted in the High Occupational Temperature Health and Productivity Suppression (HOTHAPS) programme and other empirical studies related to climate change perceptions and heat exposure impact on health, productivity and adaptation policies (Kjellstrom et al., 2009; Sheridan, 2007; Xiang et al., 2015). The modified instrument (both closed-ended and open-ended question items) focused on respondents' background characteristics, climate change risks perception, occupational heat stress experiences and adaptation strategies. The instruments were reviewed by experts and pretested in Ghana to ensure validity and reliability. The two FGDs each consisted of eight members with one group comprising individual workers of licensed SSM (FGD1) and LSM (FGD2) respectively. The primary data that emanated from the questionnaires and FGDs were complemented and validated by secondary data. Also, the average annual regional meteorological data (e.g., monthly temperature, humidity and rainfall) from two functional weather stations (Sehwi Bekwai and Tarkwa) of 50 years (1967-2017) within the study setting were obtained from the Ghana Meteorological Agency.

2.3 Data analysis

IBM Statistical Product and Service Solutions (SPSS) version 24, Microsoft Excel 2016 and XLSTAT 2018 were used to analyse the quantitative data, whereas Nvivo version 11 was used to process the qualitative data. Based on thematic analysis, the qualitative data was synthesised into themes from the text, quotes and extracts of the FGDs (Maguire and Delahunt, 2017; Ritchie et al., 2013). The themes facilitated data description and interpretation based on differences and relationships of the variables. Descriptive statistics (e.g., *M*, *SD*) and inferential statistics (e.g., Chi-Square) were employed to assess the difference in background characteristics, climate change risks perception, occupational heat stress experiences, and adaptation strategies between SSM and LSM at a significance level of $p < 0.05$. The significant difference was assessed based on the effect size criteria (very small: 0.01, small: 0.20, medium: 0.50, large: 0.80, very large: 1.20, & huge: 2.0 (Cohen, 1988; Sawilowsky, 2009). A moving average was used to handle instances of missing monthly weather data, and years with grossly incomplete data were excluded. Monthly climate data was used to calculate annual means of minimum and maximum temperatures, humidity and rainfall, with trend analysis performed using linear regression, Mann-Kendall (MK) and Sen's slope tests in XLSTAT. The MK test is widely used to assess the increasing or decreasing trend of time series data and its statistical significance, and for meteorological data characterised by outliers and missing cases (Kiros et al., 2016; Tabari et al., 2015).

3. Results

3.1 Background characteristics

The study gender composition of the study sample was 80.9% male (SSM: 55.6% vs LSM: 44.4%), 19.1% female (SSM: 27.9% vs LSM: 72.1%). The difference in the gender proportion distributed between SSM and LSM was significant ($p < 0.001$), with a small effect size. The workers' age ranged from 21 to 61 years, with a mean age of 35.1 years ($SD = 8.20$). Most (43.8%) workers were within the age group (25-34) years, followed by workers within 35-44 years (34.1%). More SSM workers (72%) were within 25-34 years compared to LSM (68%).

Most (91.9%) workers were under the age of 50 (Table 1). The difference in age distribution between SSM and LSM was not significant. Also, the variation between younger and older workers was not significant ($\chi^2(1) = 1.165$, $p = 0.304$). Most (37.8%) workers had a secondary education, which consisted of SSM (43.0%) and LSM (57.0%) workers. More workers of LSM (76.4%) compared to SSM (23.6%) had a tertiary education. All workers of SSM and none from LSM had no formal education. The difference in workers' education level between SSM and LSM was statistically significant ($p < 0.001$), with small effect size (Table 1). Furthermore, the study showed that fewer (2.6%) workers were uneducated while most (97.4%) had at least a basic education. The disparity between the uneducated and educated workers was significant (Pearson Chi-Square: ($\chi^2(1) = 11.196$, $p = 0.007$).

Years of working experience ranged from 1 to 21 years with a mean of 7.71 ($SD = 4.43$) years. Most (41.8%) respondents who had less than five years of working experience comprised equal proportions of workers from SSM (50%) and LSM (50%). While most (58.8%) SSM workers had over 10 years working experience, fewer (56.4%) LSM workers had 5-9 years working experience. The difference in years of working experience was not significant. The study also showed that most (37.5%) respondents who described their workload as heavy included SSM (40.8%) and LSM (59.2%) workers. Most workers of SSM (80.2%) and LSM (60.2%) described their workload as very heavy and medium respectively. The difference in workload between workers (SSM and LSM) was statistically significant ($p < 0.001$), with small effect size. The majority (50.3%) of respondents who worked for 11 to 13 hours comprised fewer SSM workers (21.1%) compared to LSM workers (78.9%). Workers (SSM:79.5% vs LSM: 20.5%) worked for 8 to 10 hours. There was evidence of statistically significant ($p < 0.001$) difference in working hours between SSM and LSM with a moderate effect size (Table 1).

……. **Insert Table 1: Results of the difference in mining workers' demographic and work characteristics across the type of mining activity (Chi-Square test) (n=320). Numbers in the columns refer to the number of respondents with % of respondents in parentheses**

Furthermore, most (65.9%) respondents, comprising workers who worked completely outdoors (34.3%) and mostly outdoors (32.1%), described their work environment as 'outdoor'. Workers whose workplace environment was completely outdoor comprised (SSM:34.3% vs LSM:65.7%) and completely indoor comprised (SSM:76.8% vs LSM:23.2%). The difference in workplace environment between SSM and LSM was statistically significant ($p < 0.001$) with a small effect size (Table 1). Thirty-nine percent of respondents described their job as very physically demanding (SSM:77.6% vs LSM:22.2%). However, 20.0% of SSM and 80.0% of LSM workers described their job as not at all physically demanding. The difference in job physical demands between workers (SSM and LSM) was statistically significant ($p < 0.001$) with a small effect size (Table 1). The study further revealed that most (87.2%) respondents who worked around heat sources comprised slightly more SSM (53.4%) workers than LSM workers (46.6%). The difference in working around heat sources between SSM and LSM was statistically significant ($p < 0.05$) with a very small effect size. The 29.4% of respondents who often worked around heat sources included more (79.8%) SSM workers as compared to fewer (20.2%) LSM workers; whereas the 14.7% of respondents who did not often work around heat sources comprised fewer (19.1%) SSM workers and more (80.9%) LSM workers. The difference in frequency of working around heat sources between SSM and LSM was statistically significant ($p < 0.001$) with a small effect size (Table 1).

3.2 Trend and variability of climate change indices

Descriptive statistics, trends and variability in temperature, humidity and rainfall data (1967-2017) showed evidence of climate change in the study setting (Fig's 2 - 5 & Table 2). Minimum and maximum temperatures over the period showed an increasing trend in mean values and variability. There was a significant rise in annual mean minimum and maximum temperatures of 0.027 ºC and 0.038 ºC per year respectively (Fig's 2 & 3). The MK and Sen's slope tests showed that the increasing trend in mean annual minimum and maximum temperatures were statistically significant ($p < 0.0001$) (Table 2).

…Insert Table 2. Results of descriptive statistics and trend analysis of annual climate data (1967 – 2017)

….Insert Fig 2 Trend and variations in mean maximum temperature of Western Region

….Insert Fig 3 Trend and variations in mean minimum temperature of Western Region

The data on mean annual humidity and rainfall showed a decreasing trend and decreased variability over the period (1967-2017). There was a significant reduction in annual mean humidity (-0.063) per year (Fig 4). The MK and Sen's slope tests showed that the decreasing trend in mean humidity was statistically significant ($p < 0.001$) (Table 2). The pattern of mean annual rainfall within the study area was erratic with a decreasing trend (-0.26mm) per year (Fig 5). The results of the MK and Sen's slope tests indicated that the decreasing trend in mean rainfall was not statistically significant (Table 2).

…..Insert Fig 4 Trend and variations in mean annual humidity of Western Region

…..Insert Fig 5 Trend and variations in mean annual rainfall of Western Region

3.3 Perceptions of climate change risks

The study showed that 96.6% of the respondents who were aware of climate change comprised few more (50.2%) SSM workers as compared to less (49.8%) LSM workers. The disparity in climate change awareness between SSM and LSM was not significant. Nearly 77.0% of the respondents were concerned about climate change risk effect. More respondents of SSM (87.8%) and fewer LSM (12.2%) were not at all concerned about climate change risk effect while fewer respondents of SSM (33.6%) and more LSM (66.4%) were moderately concerned about climate change risk effect. The difference in proportions of respondents with concerns about climate change risk effect between SSM and LSM was statistically significant ($p < 0.001$) with a small effect size (Table 3).

The study found that respondents' climate change awareness and associated signs and risks was informed by the occurrence of increases in temperature and hot environment (45.3%), irregular rainfall and storms (36.9%), frequent floods (6.5%) and rising sea levels (6.5%). Greater proportions of SSM workers (64.9% and 62.2%) compared to LSM (35.1% and 37.8%) identified irregular rainfall and storms, and frequent floods, as signs and effect of climate change respectively. A slightly greater proportion of LSM (51.4%) compared to SSM (48.6%) identified rising sea levels as a sign of climate change. The difference in climate change signs and effects as identified by respondents between SSM and LSM was statistically significant ($p < 0.001$), with a moderate effect size (Table 3).

The views expressed during the FGDs on climate change awareness, signs and effects over the last 30 years were similar to the findings from the questionnaire and trends in the climate data. Participants of the FGDs showed that they were aware of climate change and its associated signs and effect. A participant of the SSM workers characterised this by the following statement:

The climate has changed. When we look at the years gone by there were days the rain had its seasons. March was considered as the start of the raining seasons when it falls without any failure but this time it is not like that even in December it rains, but at certain times it changes, and at times you cannot even get the rains and the weather becomes hot.

Another respondent reiterated this sentiment with the remark:

Yes, am very much aware of climate change and the way our environment has been polluted because of the depletion of the ozone layer. Since we in Ghana lie in the tropics, the sun heat is very high, and we have a hot environment. The depleting of the ozone layer is having a negative effect on us especially the mining workers as most of our activities are outdoors and not indoors.

We asked respondents to share their thoughts on mining workers being at risk of workplace heat exposure driven by climate change. The majority (91.9%) of respondents who answered positively included workers (SSM:50.3% vs LSM:49.7%) (Table 3). The study showed that respondents associated workplace heat exposure with environmental factors including heat radiation from the sun and other sources around the workplace (37.3%), how hot the air is around the workplace (32.5%), and airspeed/movement around the workplace (17.3%). A greater proportion of workers of SSM (63.6% and 83.0%) compared to LSM (36.4% and 17.0%) identified hotness of the air around the workplace and airspeed/movement around the workplace respectively. More proportions of LSM (51.2%) compared to SSM (48.8%) respondents identified the amount of air moisture in the outdoor settings or workplaces. The difference in respondents with regards to environmental factors that influence the risk of workplace heat exposure was statistically significant ($p < 0.001$), with a moderate effect size (Table 3).

….Insert Table 3. Results of the difference in mining workers' perceptions of climate change risks across the type of mining activity (Chi-Square test) (*n* = 320).

Comparatively, participants of the FGDs corroborated the questionnaire results on the risk of workplace heat exposure to mining workers because of weather-related factors. An SSM worker who participated in the FGD illustrated the workers' risks to heat exposure due to environmental-related factors as follows:

> *As mining workers, we are exposed to the risk of heat if we do heavy work under the sun for a long time and when the wind blows occasionally, or it ceases then you feel the heat. We then drink a lot of water when we feel thirsty or take a break.*

Another FGD participant with the LSM workers summed it up in these words:

> *Mining workers are surely at risk of heat exposure especially working with the machines and also working in the sun. It produces more heat for us, and some of us who work underground we face a lot of heat. The deeper you go, the more heat you meet because the ventilation doesn't get down there to the main deep line.*

Work-related conditions based on type of physical workload (22.6%), the duration of working hours (20.3%), duration of break/rest hours (12.9%), access to drinking water (11.5%), and access to shade (11.1%) were also mentioned as factors that influence workplace heat exposure risk. There were discrepancies in proportions of respondents who identified access to drinking water (SSM:83.5% vs LSM:16.5%), type of protective clothing (SSM:38.8% vs LSM:61.2%), duration of break/rest hours (SSM:81.1% vs LSM:18.9%), and type of physical workload (SSM:43.1% vs LSM:56.9%) (Table 3). The difference in respondents who identified work-related factors that influence workplace heat exposure risk between SSM and LSM was statistically significant ($p < 0.001$) with small effect size.

Similar comments made by the discussants in the FGDs of the SSM and LSM workers showed that the risk of workers to heat exposure was associated with work-related factors (e.g., access to cooling systems, drinking water, shade, and workload). Workers' heat exposure risk due to work-related factors was explained during the FGD, as exemplified in the following vignettes:

We do heavy work under the scorching sun. Here, you will begin to sweat but if you are working under air condition or fan for hours, you will not sweat and will not feel the heat. In the open space where no tree or shade will protect you and bring you fresh air, there will be heat, and you will sweat and need to drink more water or go for a break (Participant, SSM workers).

I do agree. The nature of our work contributes to the risk of heat exposure. Like when you are working in a hot environment where you are exposed to a lot of heat, let say, the welders most at times you see them welding, and then they have provided a fan to reduce the heat that they may be exposed to, and it helps a lot. Without the fan, I don't think that they will have enough energy to complete the task assigned (Participant, LSM workers).

Considering the extent of workers' risks associated with heat exposure and climate change, respondents (69.0%) who were very much concerned about workplace heat exposure and heat stress comprised (SSM:57.0% vs LSM:43.0%). A relatively large proportion of SSM (73.3%) respondents, as compared to LSM (26.7%) were not at all concerned about workplace heat exposure. However, there were more LSM (81.1%) respondents, compared to SSM (18.9%) who were moderately concerned about workplace heat exposure. The difference in the extent of concern about workplace heat exposure and heat stress between SSM and LSM was statistically significant ($p < 0.001$) with a small effect size (Table 3).

3.4 Experiences of occupational heat stress risks

The respondents (81.3%) who had ever experienced heat-related illness comprised (SSM:51.2% vs LSM:48.8%). The difference in heat-related illness experience of respondents was not significant. Heat-related illness most frequently experienced by the workers were excessive sweating (25.1%), headaches (20.6%), heat exhaustion/tiredness (19.5%), and heat rash (14.3%). There was variation in the proportion of respondents who identified excessive sweating (SSM:68.0% vs LSM:32.0%), headache (SSM:76.0% vs LSM:35.0%), heat cramps (SSM:43.9% vs LSM:56.1%), and heat rash (SSM:83.2% vs LSM:16.8%). The difference in the proportion of respondents who identified workers' heat-related illness experience between SSM and LSM was statistically significant ($p < 0.001$) with a moderate effect size (Table 4).

Views of the discussants in the FGDs (SSM and LSM) workers on heat-related illness experiences of mining workers were headache, tiredness, excess sweat, and collapsing. For example, one discussant of SSM workers summed up their concerns of heat-related morbidity as:

> *Yeah, we sweat a lot even if you are with the 'chamfan' or if you are in the machine room. If you are exposed to heat, or you are working under the sun, you get tired easily, and if you get tired, you usually become confused and because you are tired you can get injured or hurt yourself.*

A participant of the FGD with the LSM workers explained the heat-related illness of mining workers in the following statement:

> *Yes! I have experienced some before. Like working in a place where there is heat... at the end of the job you will find yourself that you're feeling dehydrated and tired, having a*

little bit of headache and sweating. Most of our friends too, get involved in those dangers like sweating and even collapsing.

The study also revealed that respondents (70.9%) who had experienced heat-related injuries involved (SSM:52.4% vs LSM:47.6%). The variations in heat-related injury experience of workers between SSM and LSM were not statistically significant. The degree of heat-related injury mostly experienced by workers was described as minor (29.4%), moderate (18.1%) and serious (20.1%). There was a difference in the proportion of respondents between SSM and LSM who indicated minor (SSM:31.9% vs LSM:47.6%), moderate (SSM:41.4% vs LSM:58.6%) and serious (SSM:92.2% vs LSM:7.8%). The difference in the proportion of respondents who identified workers' heat-related injury experience between SSM and LSM was statistically significant ($p < 0.001$) with small effect size (Table 4).

….Insert Table 4. Results of the difference in mining workers' experiences of occupational heat stress risks across the type of mining activity (Chi-Square test) (*n* = 320).

Furthermore, the respondents specified the type of heat-related injuries of workers as being hit by objects (19.4%), hitting objects (18.3%), fall, trips, and slips due to dizziness, fainting, and fatigue (11.7%) and burns from hot objects/surfaces (11.0%). The instances of variation in proportion of respondents who stated being hit by objects (SSM:88.4% vs LSM:11.6%), hitting objects (SSM:76.5% vs LSM:23.5%), fall, trips, and slips due to dizziness, fainting, and fatigue (SSM:61.5% vs LSM:38.5%), and burns from hot objects (SSM:42.9% vs LSM:57.1%) was statistically significant ($p < 0.001$) with a moderate effect size.

Respondents were asked if they had witnessed any form of heat-related injury to another mining worker; 82.8% comprising (SSM:52.8% vs LSM:47.3%) answered in the affirmative. The difference in the proportion of respondents who witnessed a heat-related injury to another mining worker between SSM and LSM was statistically significant ($p < 0.05$) with very small effect size. The respondents stated the type of heat-related injuries witnessed to mining workers as being hit by objects (21.9%), hitting objects (20.0%), fall, trips, and slips due to dizziness, fainting, and fatigue (18.1%) and burns from hot objects/surfaces (13.1%). The variation in proportion of respondents who stated being hit by objects (SSM:83.7% vs LSM:16.3%), hitting objects (SSM:71.6% vs LSM:28.4%), fall, trips, and slips due to dizziness, fainting, and fatigue (SSM:62.8% vs LSM:37.2%), and burns from hot objects (SSM:35.5% vs LSM:64.5%) as the type of heat-related injury witnessed was statistically significant ($p < 0.001$) with a moderate effect size.

3.5 Preventive and control measures of occupational heat stress due to climate change

Figure 6 illustrates the preventive and control measures of occupational heat stress due to climate change among mining workers. The study showed that the respondents (82.8%) who were aware of preventive and control measures comprised (SSM:47.6% vs LSM:52.4%). The difference in the proportion of respondents who were aware of preventive and control measures of occupational heat stress due to climate change between SSM and LSM was statistically significant ($p < 0.05$) with very small effect size. The preventive and control measures of occupational heat stress mostly used by workers included drinking adequate water (40.2%), using air conditioners and fans (27.0%), and taking work breaks and resting in the shade (18.8%). The variation in proportion of respondents across the type of mining activity who stated drinking adequate water (SSM: 50.5% vs. LSM: 49.5%), using air conditioners and fans (SSM: 66.2% vs. LSM: 33.8%), and taking work breaks and resting in shade (SSM: 45.5% vs. LSM: 54.5%) was statistically significant ($p < 0.05$) with a small effect size (Fig 7).

Insert Fig 6. Results of the difference in mining workers' awareness of preventive and control measures of occupational heat stress due to climate change across the type of mining activity (Chi-Square test) (*n* = 320)

Insert Fig 7. Results of the difference in mining workers' preventive and control measures of occupational heat stress due to climate change across the type of mining activity (Chi-Square test) (*n* = 527*)

Similarly, evidence from the FGDs re-echoed workers' awareness and use of cooling systems, drinking water, rest-break regimes, and clothing to prevent and control occupational heat stress due to climate change. This is evident in the following extracts from the FGDs with SSM and LSM workers.

> *When we are going down [underground], we use the blower to blow air into it for a about thirty minutes to one hour. To protect us from injury and heat while working, you wear shirts that are light that will allow air to penetrate it to help you not to feel the heat. If you are working underground, you frequently drink water (Participant, SSM workers).*

> *We work on the surface in the sun or underground, the strategy is that we break for a while like an hour and cool ourselves in the offices where we do the paperwork. The things we do to protect ourselves are the water we drink, the air conditions and go to cool place to have fresh air for a while before we continue the work (Participant, LSM workers).*

4. Discussion

This study is the first to apply a mixed method approach to assess the perceptions of climate change and occupational heat stress risks and adaptation strategies of mining workers in Ghana. The study relies on the results of a self-reported survey and FGDs among the workers (SSM and LSM), complemented by trends and variability of meteorological data in the study setting. The results were related to conceptual and empirical studies to provide a comprehensive understanding of mining workers' demographic and work characteristics, climate change risks perceptions, occupational heat stress risks, and adaptation strategies to inform policy decisions in the mining industry.

4.1 Demographic and work characteristics

Differences in the demographics of workers (e.g., gender and education level) between SSM and LSM that were significant should be considered in climate change and heat stress risk management policy deliberations. Though younger males with secondary school qualification dominated the mining sector, more males worked in SSM compared to LSM. Gender inequality in the mining sector is due to its typical male dominance (Abrahamsson et al., 2014; ABS, 2016; Bowers et al., 2018). More SSM workers had no formal education whereas more LSM workers had tertiary education. Younger workers with less sense of vulnerability as compared to older colleagues tend to work more hours for higher pay without recourse to the risk of heat-related illness, reduced productive capacity and disrupted social well-being (Jia et al., 2016; Xiang et al., 2014). The educated and younger workers' behaviour and attitude should inform occupational health and safety policies to promote workers' adaptive capacity and resilience.

The significant differences in work characteristics (e.g., workload, working hours, physical demands of jobs, working around heat sources and frequency of working around heat sources) between SSM and LSM workers has implications for sustainable and strategic utilisation of workers in the context of intensifying temperature and climate change. The significant variations between SSM and LSM in demographic and work factors should mirror workplace strategies meant to reduce the magnitude of heat exposure and promote workers' adaptive capacity. The policies should include a reduction in workload, working hours on hot days, physically exerting jobs, the frequency of working close to heat sources, and continued education, information and training of workers on heat exposure and adaptation.

4.2 Perceptions of climate change risks

Overall, the workers were reasonably aware of climate change and had serious anxieties about its risks and effects. Similar studies substantiate adequate knowledge and awareness of climate change and concerns of its risk among people and workers in various regions around the world (e.g., Baptiste, 2017; Brechin and Bhandari, 2011; Frimpong et al., 2015; Pugliese and Ray, 2009; Thomas and Benjamin, 2018). The evidence of significant variation found in workers' concerns about climate change risk effect is likely due to differences in the educational attainment of workers and should be valuable for policy decisions in reducing climate change risk as most of the workers are educated and younger. Educational attainment has been found to be a good predictor of climate change awareness and concerns of people (Ajuang et al., 2016; Knight, 2016; Lee et al., 2015; Mattah et al., 2018).

The workers' high level of awareness of climate change was explained by observed markers including increase in temperature, hot environment, erratic rainfall, frequent floods, and rising sea levels. The workers' assertions were supported by the significant increasing trend in mean annual temperature, decreasing trend in mean annual humidity, and an erratic and slightly decreasing trend in rainfall pattern recorded in the study area over the last 50 years. The findings on significant disparity in the signs and effect of climate change between SSM and LSM are noteworthy in policy consideration at reducing climate change risk. The workers' awareness of climate change markers corroborates recent studies in which increasing temperature, humidity, irregular rainfall, rising sea levels, and prolonged droughts and storms were given as examples of climate change (Evadzi et al., 2018; Hoogendoorn and Fitchett, 2018; van Oldenborgh et al., 2018).

Workers' risk of workplace heat exposure is due to environmental, personal, and occupational-related heat exposure risks factors (Kjellstrom et al., 2016a; Parsons, 2014; Schulte and Chun, 2009). The important difference in environmental factors (e.g., heat radiation from the sun and other sources, hot air, and airspeed/movement) which influenced workers' risk of workplace heat exposure are essential for strategic options aimed at adaptation or reducing the magnitude of outdoor heat exposure of workers. Similarly, intensifying ambient temperature, radiant heat, relative humidity, and reduced air movement are notable weather-related factors that influence work-related heat exposure (Kjellstrom et al., 2009; Parsons, 2014; Schulte and Chun, 2009). Furthermore, the significant variations between SSM and LSM in work-related conditions (e.g., type of physical workload, duration of working hours, duration of break/rest hours, access to drinking water, and shades) which influenced workers' risk of workplace heat exposure should be used to shape different climate change adaptation and workplace heat management policies for these two groups of workers. Multiple studies found break hours, work-rest regimes, access to shade, physical activity, cooling system, clothing type, and drinking water as factors that influence heat exposure (Haines and Patz, 2004; Kjellstrom et al., 2016a; McMichael et al., 2006). Similarly, the significant difference in the extent of concern about workplace heat exposure between SSM and LSM are worthy of consideration for an effective workplace heat management policy as majority of the workers are educated.

Thus, effective and sustained policies to climate change risk hinge on workers' perceived and actual knowledge of climate change and heat exposure risks (Ford et al., 2010; Kjellstrom et al., 2016a; Tripathi and Mishra, 2017). Workers' awareness of climate change risk, information and communication are important for policy making and implementation, particularly to any strategic response to combating climate change impacts (Aswani et al., 2015; Carlton and Jacobson, 2013; Hagen et al., 2016).

4.3 Occupational heat stress risk experience

Many workers experienced heat-related morbidity. However, the difference in workers' heat-related morbidity experiences between SSM and LSM was not significant. The type of heat-related illness experienced by workers were commonly reported in similar studies in different work environments (Krishnamurthy et al., 2017; Lao et al., 2016; Stoecklin-Marois et al., 2013). The significant variations in the type of personal or witnessed heat-related injury experiences of workers (e.g., being hit by objects, hitting objects, falls, trips, and slips due to dizziness, fainting, and fatigue, and burns from hot objects/surfaces) between SSM and LSM are important factors to be taken into account when framing policy to protect workers against heat stress hazards. As with studies among mining supervisors in Ghana (Nunfam et al., 2018), the degree of heat-related injury experience of most workers was described as minor. The variation in the extent of injury experience of workers between SSM and LSM was significant as more workers of LSM experienced minor to moderate injuries while more SSM workers experienced serious injuries. However, other studies (Tawatsupa et al., 2013; Xiang et al., 2016) described the extent of workers' heat-related injuries as moderate to serious.

Comparable findings on the type of injury experienced by workers due to heat exposure were recounted in other studies (Tawatsupa et al., 2013; Varghese et al., 2018; Xiang et al., 2016). The evidence of significant variations in the workers' experiences of heat-related injuries, the magnitude of injuries, and the type of personal or witnessed injuries was likely due to variations in workload, length of working hours, work environment conditions, work physical demands, and frequency of working around heat sources across the type of mining activity. The extent of workers' awareness of occupation heat stress, as corroborated by other studies, and the variation in heat-related morbidity experiences across the type of mining activity illustrates the extent of heat exposure risk due to rising temperature and climate change (Government of Ghana, 2013, 2015; Xiang et al., 2016). Therefore, workplace policies and procedures aimed at ensuring workers' health, safety and effective performance need to incorporate the identified occupational heat stress risk concerns of workers to promote appropriate workload, working hours, and work environments devoid of heat stress risk.

4.4 Preventive and control strategies of occupational heat stress due to climate change

Occupational heat stress is manageable with awareness and enforcement of standards for assessing and monitoring occupational heat-related hazards among workers (NIOSH, 2016; Parsons, 2013). Most workers were aware and often used measures (such as drinking adequate water, air conditioners and fans, taking work breaks and resting in shades) to manage occupational heat stress. However, more workers of SSM than LSM experienced the use of loose and light-coloured clothing, taking work breaks and resting in shades. The significant difference in workers' awareness and use of preventive and control measures of occupational heat stress due to climate change between SSM and LSM are important indicators for heat adaptation strategies. The results of the study as reiterated in several studies corroborate the usefulness of workers' knowledge and effective use of coping and adaptation policies (e.g., housing designs, drinking water, break/rest regimes, use of cooling systems, and type of clothing) (Lao et al., 2016; Pradhan et al., 2013; Xiang et al., 2015). Mitigation and adaptation policies of climate change-related heat stress mainly include engineering solutions, administrative controls, education and training regimes, compensation, and social protection of workers (Davies et al., 2009; Kjellstrom et al., 2016b; NIOSH, 2016). Enhancing awareness and implementing heat stress management strategies among workers has the significant implication of boosting adaptive capacity and resilience and improving policy decisions for combating heat stress due to rising temperature and climate change impacts.

5. Conclusions and implications for policy decisions

Workers of both SSM and LSM were reasonably aware of climate change and its effects, and their views agreed with the measured trend and variability of climate data in the study setting. The utilisation of preventive and control measures to reduce occupational heat stress due to high temperature and climate change was based on workers' experiences and concerns of heat-related morbidity. Workers' concerns about climate change and workplace heat exposure risks, experiences of the type of heat-related morbidities, and awareness and use of adaptation strategies differed significantly between SSM and LSM. The observed differences between the type of mining activity include workers' gender, educational attainment, workload, working hours, physical job exertion, and working near heat sources. Similar disparities include workers' exposure to heat radiation, hot air, and air speed as well as work-related factors such as break/rest hours, access to drinking water, and type of protective clothing. Other variations are the type of heat-related injury experiences, use of clothing, drinking sufficient water, use of cooling systems, and resting in shade. Workplace policies on health and safety, heat stress management, and workers' adaptive capacity in the mining sector should be informed by these inconsistencies. Mining workers and other stakeholders should be part of the main focus of occupational heat stress and climate change adaptation intervention and planning to manage the risk climate change poses to their lives and livelihood. Hence, a concerted effort among stakeholders is required to promote mining workers' health and safety, productive capacity, and effective performance and to enhance their adaptive capacity and inform policy decisions and enforcement in the mining industry.

Acknowledgements

This manuscript is part of a PhD research project at ECU. We thank the study participants for their willingness and informed consent during the study. We also acknowledge the support of the ECU Higher Degree by Research Scholarship (HDRS) for the provision of a PhD scholarship and the Human Research Ethics Committee of ECU (Project Number 17487) for ethical clearance. We are most grateful for the important remarks and suggestions of the anonymous reviewers.

Conflict of interest

None

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors

References

Abrahamsson, L., Segerstedt, E., Nygren, M., Johansson, J., Johansson, B., Edman, I., Åkerlund, A., 2014. Mining and Sustainable Development: Gender, Diversity and Work Conditions in Mining. http://www.diva-portal.org/smash/get/diva2:995297/FULLTEXT01.pdf

ABS., 2016. *Labour Force, Australia, Detailed, Quarterly*. Retrieved from http://www.abs.gov.au/ausstats/abs@.nsf/mf/6291.0.55.003

Ajuang, C. O., Abuom, P. O., Bosire, E. K., Dida, G. O., Anyona, D. N., 2016. Determinants of climate change awareness level in upper Nyakach Division, Kisumu County, Kenya. *SpringerPlus, 5*(1), 1015. https://doi:10.1186/s40064-016-2699-y

Arbury, S., Jacklitsch, B., Farquah, O., Hodgson, M., Lamson, G., Martin, H., Profitt, A., 2014. Heat Illness and Death Among Workers - United States, 2012-2013. *Mmwr-Morbidity and Mortality Weekly Report, 63*(31), 661-665. doi:http://europepmc.org/articles/pmc4584656.

Aswani, S., Vaccaro, I., Abernethy, K., Albert, S., de Pablo, J. F.-L., 2015. Can perceptions of environmental and climate change in island communities assist in adaptation planning locally? *Environ Manage, 56*(6), 1487-1501. https://link.springer.com/article/10.1007/s00267-015-0572-3

Ayyappan, R., Sankar, S., Rajkumar, P., Balakrishnan, K., 2009. Work-related heat stress concerns in automotive industries: a case study from Chennai, India. *Global Health Action, 2*, 58-64. https://doi:10.3402/gha.v2i0.2060

Balakrishnan, K., Ramalingam, A., Dasu, V., Stephen, J. C., Sivaperumal, M. R., Kumarasamy, D., . . . Sambandam, S., 2010. Case studies on heat stress related perceptions in different industrial sectors in southern India. *Global Health Action, 3*. https://doi:10.3402/gha.v3i0.5635

Baptiste, A. K., 2017. Climate change knowledge, concerns, and behaviours among Caribbean fishers. *Journal of Environmental Studies and Sciences, 8*(1), 51-62. https://doi:10.1007/s13412-017-0434-9

Bernard, H. R., 2017. *Research methods in anthropology: Qualitative and quantitative approaches* (6 ed.). London: Rowman & Littlefield.

Bowers, J., Lo, J., Miller, P., Mawren, D., Jones, B., 2018. Psychological distress in remote mining and construction workers in Australia. *Med J Aust, 208*(9), 391-397. https://www.mja.com.au/system/files/issues/208_09/10.5694mja17.00950.pdf

Brechin, S. R., Bhandari, M., 2011. Perceptions of climate change worldwide. *Wiley Interdisciplinary Reviews-Climate Change, 2*(6), 871-885. https://doi:10.1002/wcc.146

Carlton, S. J., Jacobson, S. K., 2013. Climate change and coastal environmental risk perceptions in Florida. *J Environ Manage, 130*, 32-39. https://doi:10.1016/j.jenvman.2013.08.038

CDC. (2008). Heat-related deaths among crop workers-United States, 1992-2006. *MMWR: Morbidity and mortality weekly report, 57*(24), 649-653.

Cohen, J., 1988. *Statistical power analysis for the behavioural sciences* (2 ed.). Hillsdale, NJ: Erlbaum Associates.

Creswell, J. W., 2013. *Research design: Qualitative, quantitative, and mixed methods approaches*. London: Sage publications.

Creswell, J. W., Clark, V. L. P., 2017. *Designing and conducting mixed methods research* (3rd ed.). London: Sage publications.

Crowe, J., van Wendel de Joode, B., Wesseling, C., 2009. A pilot field evaluation on heat stress in sugarcane workers in Costa Rica: What to do next? *Glob Health Action, 2*. https://doi:10.3402/gha.v2i0.2062

Davies, M., Oswald, K., IDS, T. M., 2009. Climate change adaptation, disaster risk reduction and social protection. *Unclassified DCD/DAC (2009) 15/ADD*, 141. https://doi.org/10.1111/j.2040-0209.2009.00320_2.x

Dunne, J. P., Stouffer, R. J., John, J. G., 2013. Reductions in labour capacity from heat stress under climate warming. *Nature Climate Change, 3*(6), 563-566. https://www.nature.com/articles/nclimate1827doi:10.1038/nclimate1827

Evadzi, P. I. K., Scheffran, J., Zorita, E., Hunicke, B., 2018. Awareness of sea-level response under climate change on the coast of Ghana. *Journal of Coastal Conservation, 22*(1), 183-197. http://doi:10.1007/s11852-017-0569-6

Flocks, J., Vi Thien Mac, V., Runkle, J., Tovar-Aguilar, J. A., Economos, J., McCauley, L. A., 2013. Female farmworkers' perceptions of heat-related illness and pregnancy health. *J Agromedicine, 18*(4), 350-358. https://doi:10.1080/1059924X.2013.826607

Ford, J. D., Pearce, T., Prno, J., Duerden, F., Ford, L. B., Beaumier, M., Smith, T., 2010. Perceptions of climate change risks in primary resource use industries: a survey of the Canadian mining sector. *Regional Environmental Change, 10*(1), 65-81. https://doi:10.1007/s10113-009-0094-8

Frimpong, K., van Etten, E., Oosthuzien, J., & Nunfam, V. F. (2015). Review of climate change adaptation and social protection policies of Ghana: the extent of reducing impacts of climate change and heat stress vulnerability of smallholder farmers. *International Journal of Social Ecology and Sustainable Development (IJSESD), 6*(4), 1-14. https://www.igi-global.com/article/review-of-climate-change-adaptation-and-social-protection-policies-of-ghana/142144doi:10.4018/IJSESD.2015100101

Ghana Chamber of Mines (GCM), 2015. *Performance of the Mining Industry in 2015*. Retrieved from Accra: Retrieved from https://ghanachamberofmines.org/media-press/our-publications/

Government of Ghana, 2013. *Ghana National Climate Change Policy 2013*. Accra, Ghana: Government of Ghana Retrieved from http://www.un-page.org/files/public/ghanaclimatechangepolicy.pdf.

Government of Ghana, 2015. *Ghana's Third National Communication Report to the UNFCCC*. Accra, Ghana: MESTI, Government of Ghana Retrieved from https://unfccc.int/resource/docs/natc/ghanc3.pdf.

Hagen, B., Middel, A., Pijawka, D., 2016. European climate change perceptions: public support for mitigation and adaptation policies. *Environmental Policy and Governance, 26*(3), 170-183. https://doi:10.1002/eet.1701

Haines, A., Patz, J. A., 2004. Health effects of climate change. *JAMA, 291*(1), 99-103. https://doi:10.1001/jama.291.1.99

Hoogendoorn, G., Fitchett, J. M., 2018. Tourism and climate change: a review of threats and adaptation strategies for Africa. *Current Issues in Tourism, 21*(7), 742-759. https://doi:10.1080/13683500.2016.1188893

IPCC., 2001. *Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change* (James J. McCarth, Osvaldo F. Canziani, Neil A. Leary, David J. Dokken, & Kasey S. White Eds.). Cambridge, United Kingdom and New York, NY, USA,: Cambridge University Press.

IPCC., 2014a. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (V. R. Barros, C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, a. P.R. Mastrandrea, & L. L. White Eds.). Cambridge University Press, Cambridge,: United Kingdom and New York, NY, USA, .

IPCC., 2014b. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Retrieved from Cambridge, United Kingdom and New York, NY, USA,. https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_All_Topics.pdf

IPCC., 2014c. *Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Retrieved from Cambridge, United Kingdom and New York, NY, USA,: http://ipcc-wg2.gov/AR5/images/uploads/WG2AR5_SPM_FINAL.pdf

Jacklitsch, B. L., 2017. *Assessing Heat-Related Knowledge, Perceptions, and Needs among Emergency Oil Spill Cleanup Responders.* The University of Cincinnati. Retrieved from http://rave.ohiolink.edu/etdc/view?acc_num=ucin1509983799665014

Jia, Y. A., Rowlinson, S., Ciccarelli, M., 2016. Climatic and psychosocial risks of heat illness incidents on construction site. *Appl Ergon, 53 Pt A*, 25-35. doi:10.1016/j.apergo.2015.08.008

Kiros, G., Shetty, A., Nandagiri, L., 2016. Analysis of variability and trends in rainfall over northern Ethiopia. *Arabian Journal of Geosciences, 9*(6), 451. https://doi:ARTN45110.1007/s12517-016-2471-1

Kjellstrom, T., Briggs, D., Freyberg, C., Lemke, B., Otto, M., Hyatt, O., 2016a. Heat, Human Performance, and Occupational Health: A Key Issue for the Assessment of Global Climate Change Impacts. *Annu Rev Public Health, 37*, 97-112. https://doi:10.1146/annurev-publhealth-032315-021740

Kjellstrom, T., Gabrysch, S., Lemke, B., Dear, K., 2009. The 'Hothaps' programme for assessing climate change impacts on occupational health and productivity: an invitation to carry out field studies. *Glob Health Action, 2*. https://doi:10.3402/gha.v2i0.2082

Kjellstrom, T., Holmer, I., Lemke, B., 2009. Workplace heat stress, health and productivity - an increasing challenge for low and middle-income countries during climate change. *Glob Health Action, 2*, 46-51. https://doi:10.3402/gha.v2i0.2047

Kjellstrom, T., Otto, M., Lemke, B., Hyatt, O., Briggs, D., Freyberg, C., Lines, L., 2016b. *Climate change and labour: Impacts of heat in the workplace climate change, workplace environmental conditions, occupational health risks, and productivity –an emerging global challenge to decent work, sustainable development and social equity.* Retrieved from http://www.ilo.org/wcmsp5/groups/public/---ed_emp/---gjp/documents/publication/wcms_476194.pdf

Knight, K. W., 2016. Public awareness and perception of climate change: a quantitative cross-national study. *Environmental Sociology, 2*(1), 101-113. https://doi:10.1080/23251042.2015.1128055

Krishnamurthy, M., Ramalingam, P., Perumal, K., Kamalakannan, L. P., Chinnadurai, J., Shanmugam, R., . . . Venugopal, V., 2017. Occupational heat stress impacts on health and productivity in a steel industry in Southern India. *Safety and Health at Work, 8*(1), 99-104. https://dx.doi.org/10.1016/j.shaw.2016.08.005

Lao, J., Hansen, A., Nitschke, M., Hanson-Easey, S., Pisaniello, D., 2016. Working smart: An exploration of council workers' experiences and perceptions of heat in Adelaide, South Australia. *Safety Science, 82*, 228-235. https://dx.doi.org/10.1016/j.ssci.2015.09.026

Leal Filho, W., Azeiteiro, U., Alves, F., Pace, P., Mifsud, M., Brandli, L., . . . Disterheft, A., 2018. Reinvigorating the sustainable development research agenda: the role of the sustainable development goals (SDG). *International Journal of Sustainable Development & World Ecology, 25*(2), 131-142. https://doi.org/10.1080/13504509.2017.1342103

Lee, T. M., Markowitz, E. M., Howe, P. D., Ko, C. Y., Leiserowitz, A. A., 2015. Predictors of public climate change awareness and risk perception around the world. *Nature Climate Change, 5*(11), 1014-+. https://doi:10.1038/Nclimate2728

Maguire, M., Delahunt, B., 2017. Doing a thematic analysis: A practical, step-by-step guide for learning and teaching scholars. *AISHE-J: The All Ireland Journal of Teaching and Learning in Higher Education, 9*(3). https://ojs.aishe.org/aishe/index.php/aishe-j/article/view/335

Mattah, P. A. D., Futagbi, G., Mattah, M. M., 2018. Awareness of environmental change, climate variability, and their role in prevalence of mosquitoes among urban dwellers in

Southern Ghana. *Journal of Environmental and Public Health, 2018*. https://doi:Artn 534262410.1155/2018/5342624

McMahon, G., Moreira, S., 2014. The contribution of the mining sector to socioeconomic and human development. doi:https://openknowledge.worldbank.org/bitstream/handle/10986/18660/872980nwp0mini00box385186b00public0.pdf?sequence=1

McMichael, A. J., Woodruff, R. E., Hales, S., 2006. Climate change and human health: present and future risks. *Lancet, 367*(9513), 859-869. https://doi:10.1016/S0140-6736(06)68079-3

McQuilken, J., & Hilson, G., 2016. *Artisanal and small-scale gold mining in Ghana Evidence to inform an 'action dialogue'*. Retrieved from London: http://pubs.iied.org/16618IIED/

Mertens, D. M., 2015. Mixed methods and wicked problems. *Journal of Mixed Methods Research, 9*(1), 3-6. https://doi:10.1177/1558689814562944

NIOSH., 2016. *NIOSH criteria for a recommended standard: occupational exposure to heat and hot environments*. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health Retrieved from https://www.cdc.gov/niosh/docs/2016-106/pdfs/2016-106.pdf 26/10/2017

Nunfam, V. F., Adusei-Asante, K., Van Etten, E. J., Oosthuizen, J., Frimpong, K., 2018. Social impacts of occupational heat stress and adaptation strategies of workers: A narrative synthesis of the literature. *Science of the Total Environment, 643*, 1542-1552. doi:https://doi.org/10.1016/j.scitotenv.2018.06.255

Nunfam, V. F., Van Etten, E. J., Oosthuizen, J., Adusei-Asante, K., Frimpong, K., 2018. Climate change and occupational heat stress risks and adaptation strategies of mining workers: Perspectives of supervisors and other stakeholders in Ghana. *Environmental research*. doi: https://doi.org/10.1016/j.envres.2018.11.004

Park, J., Kim, Y., Oh, I., 2017. Factors affecting heat-related diseases in outdoor workers exposed to extreme heat. *Ann Occup Environ Med, 29*(1), 30. doi:10.1186/s40557-017-0183-y

Parsons, K., 2013. Occupational health impacts of climate change: current and future ISO standards for the assessment of heat stress. *Ind Health, 51*(1), 86-100. https://doi.org/10.2486/indhealth.2012-0165

Parsons, K., 2014. *Human thermal environments: the effects of hot, moderate, and cold environments on human health, comfort, and performance* (3 ed.). Boca Raton, NewYork and London: CRC Press.

Pradhan, B., Shrestha, S., Shrestha, R., Pradhanang, S., Kayastha, B., Pradhan, P., 2013. Assessing climate change and heat stress responses in the Tarai region of Nepal. *Industrial Health, 51*(1), 101-112. https://doi.org/10.2486/indhealth.2012-0166

Pugliese, A., Ray, J., 2009. A heated debate: global attitudes toward climate change. *Harvard International Review, 31*(3), 64. https://search.proquest.com/docview/230941451/fulltext/71E78B21BDC14B6BPQ/1?accountid=10675

Ritchie, J., Lewis, J., Nicholls, C. M., Ormston, R., 2013. *Qualitative research practice: A guide for social science students and researchers* (2 ed.). Los Angeles: Sage.

Sawilowsky, S. S., 2009. New Effect Size Rules of Thumb. *Journal of Modern Applied Statistical Methods, 8*(2), 597-599. https://doi:10.22237/jmasm/125703510

Sheridan, S. C., 2007. A survey of public perception and response to heat warnings across four North American cities: an evaluation of municipal effectiveness. *International Journal* *of Biometeorology, 52*(1), 3-15. https://link.springer.com/article/10.1007/s00484-006-0052-9

Schulte, P. A., Chun, H., 2009. Climate change and occupational safety and health: establishing a preliminary framework. *J Occup Environ Hyg, 6*(9), 542-554. https://doi:10.1080/15459620903066008

Stoecklin-Marois, M., Hennessy-Burt, T., Mitchell, D., Schenker, M., 2013. Heat-related illness knowledge and practices among California hired farm workers in the MICASA study. *Industrial Health, 51*(1), 47-55. https://doi.org/10.2486/indhealth.2012-0128

Tabari, H., Taye, M. T., Willems, P., 2015. Statistical assessment of precipitation trends in the upper Blue Nile River basin. *Stochastic Environmental Research and Risk Assessment, 29*(7), 1751-1761. https://doi:10.1007/s00477-015-1046-0

Tawatsupa, B., Yiengprugsawan, V., Kjellstrom, T., Berecki-Gisolf, J., Seubsman, S. A., Sleigh, A., 2013. Association between heat stress and occupational injury among Thai workers: findings of the Thai cohort study. *Industrial Health, 51*(1), 34-46. https://doi:10.2486/indhealth.2012-0138

Thomas, A., Benjamin, L., 2018. Perceptions of climate change risk in The Bahamas. *Journal of Environmental Studies and Sciences, 8*(1), 63-72. https://doi.org/10.1007/s13412-017-0429-6

Tripathi, A., Mishra, A. K., 2017. Knowledge and passive adaptation to climate change: An example from Indian farmers. *Climate Risk Management, 16*, 195-207. https://doi:10.1016/j.crm.2016.11.002

United Nations (UN)., 2015. *Transforming our world: the 2030 Agenda for Sustainable Development*. Retrieved from New York: United Nations: https://sustainabledevelopment.un.org/post2015/transformingourworld/publication van Oldenborgh, G. J., Philip, S., Kew, S., van Weele, M., Uhe, P., Otto, F., . . . AchutaRao, K., 2018. Extreme heat in India and anthropogenic climate change. *Natural Hazards and Earth System Sciences, 18*(1), 365-381. https://doi:10.5194/nhess-18-365-2018

Varghese, B. M., Hansen, A., Bi, P., Pisaniello, D., 2018. Are workers at risk of occupational injuries due to heat exposure? A comprehensive literature review. *Safety Science*. https://doi.org/10.1016/j.ssci.2018.04.027

Xiang, J., Bi, P., Pisaniello, D., Hansen, A., 2014. Health impacts of workplace heat exposure: an epidemiological review. *Ind Health, 52*(2), 91-101. https://doi.org/10.2486/indhealth.2012-0145.

Xiang, J., Hansen, A., Pisaniello, D., Bi, P., 2015. Perceptions of workplace heat exposure and controls among occupational hygienists and relevant specialists in Australia. *PloS One, 10*(8), e0135040. https://doi:10.1371/journal.pone.0135040

Xiang, J., Hansen, A., Pisaniello, D., Bi, P., 2016. Workers' perceptions of climate change-related extreme heat exposure in South Australia: a cross-sectional survey. *BMC Public Health, 16*(1), 549. https://doi:10.1186/s12889-016-3241-4

Zander, K. K., Botzen, W. J., Oppermann, E., Kjellstrom, T., Garnett, S. T., 2015. Heat stress causes substantial labour productivity loss in Australia. *Nature Climate Change, 5*(7), 647. https://www.nature.com/articles/nclimate2623doi:10.1038/nclimate2623

Zander, K. K., et al., 2017. Drivers of self-reported heat stress in the Australian labour force. *Environ Res, 152*, 272-279. https://doi.org/10.1016/j.envres.2016.10.029

Tables 1 to 4

Table 1. Results of the difference in mining workers' demographic and work characteristics across the type of mining activity (Chi-Square test) (n=320). Numbers in the columns refer to the number of respondents with % of respondents in parentheses

Characteristics	Type of mining activity SSM F(%)	LSM F(%)	Total F(%)
Sex			
Male	144(55.6)	115(44.4)	259(80.9)
Female	17(27.9)	44(72.1)	61(19.1)
Pearson Chi-Square: (χ^2(1)= 15.186, p< 0.001, Cramer's V= 0.218)			
Age group (M= 35.1; SD= 8.20)			
< 25	16(59.3)	11(40.7)	27(8.4)
25-34	72(51.4)	68(48.6)	140(43.8)
35-44	52(47.7)	57(52.3)	109(34.1)
45-54	18(51.4)	17(48.6)	35(10.9)
55+	3(33.3)	6(66.7)	9(2.8)
Pearson Chi-Square: (χ^2(1)= 2.286, p= 0.683)			
Level of education			
No formal education	9(100.0)	0(0.0)	9(2.8)
Basic education	79(78.2)	22(21.8)	101(31.6)
Secondary education	52(43.0)	69(57.0)	121(37.8)
Tertiary education	21(23.6)	68(76.4)	89(27.8)
Pearson Chi-Square: (χ^2(3)= 68.367, p= 0.001, Cramer's V= 0.462)			
Years of working experience (M= 7.71; SD= 4.434)			
<5	67(50.0)	67(50.0)	134(41.8)
5-9	44(43.6)	57(56.4)	101(31.6)
10+	50(58.8)	35(41.2)	85(26.6)
Pearson Chi-Square: (χ^2(2)= 4.308, p= 0.116)			
Workload			
Light	8(38.1)	13(61.9)	21(6.6)
Medium	39(39.8)	59(60.2)	98(30.6)
Heavy	49(40.8)	71(59.2)	120(37.5)
Very heavy	65(80.2)	16(19.8)	81(25.3)
Pearson Chi-Square: (χ^2(3)= 38.936, p= 0.001, Cramer's V= 0.349)			
Working hours			
8-10	124(79.5)	32(20.5)	156(48.8)
11-13	34(21.1)	127(78.9)	161(50.3)
14-16	3(100.0)	0(0.0)	3(0.9)
Pearson Chi-Square: (χ^2(2)= 110.969, p= 0.001, Cramer's V= 0.589)			
Workplace environment			
Completely outdoor	37(34.3)	71(65.7)	108(33.8)
Mostly outdoor	57(55.3)	46(44.7)	103(32.1)
Completely indoor	53(76.8)	16(23.2)	69(21.6)
Mostly indoor	14(35.0)	26(65.0)	40(12.5)
Pearson Chi-Square: (χ^2(3)= 35.308, p= 0.001, Cramer's V= 0.332)			
Job physically demanding			
Not at all	12(20.0)	48(80.0)	60(18.7)
Very little	16(31.4)	35(68.6)	51(15.9)
Moderate	36(42.9)	48(57.1)	84(26.3)
Very much	97(77.6)	28(22.4)	125(39.1)
Pearson Chi-Square: (χ^2(3)= 68.471, p= 0.001, Cramer's V= 0.463)			
Working around heat sources			
Yes	149(53.4)	130(46.6)	279(87.2)
No	12(29.3)	29(70.7)	41(12.8)
Pearson Chi-Square: (χ^2(1)= 8.331, p= 0.004, *Phi*= 0.161)			
Frequency of work around heat sources			
Never	5(62.5)	3(37.5)	8(2.5)
Not often	9(19.1)	38(80.9)	47(14.7)
Sometimes	26(34.7)	49(65.3)	75(23.4)
Often	75(79.8)	19(20.2)	94(29.4)
Always	34(59.6)	23(40.4)	57(17.8)
No response	12(30.8)	27(69.2)	39(12.2)
Pearson Chi-Square: (χ^2(5)= 66.691, p= 0.001, Cramer's V= 0.457)			

Source: Field survey, 2017

Table 2. Results of descriptive statistics and trend analysis of annual climate data (1967 – 2017)

Variables	Min	Max	*M*	*SD*	MK's tau	Sen's slope	*p*-value	Confidence interval
T Min	21.5	23.9	22.5	0.551	0.511	0.027	<0.0001*	0.025-0.028
T Max	31.1	33.2	32.4	0.647	0.679	0.038	<0.0001*	0.036-0.040
Humidity	91.0	97.9	93.6	1.597	-0.358	-0.053	0.000*	-0.061-0.044
Rainfall	88.1	238	121	21.8	-0.042	-0.050	0.667	-0.128-0.012

*Two-tailed test at significance level ($p < 0.05$)

Source: Authors, 2017

Table 3. Results of the difference in mining workers' perceptions of climate change risks across the type of mining activity (Chi-Square test) (n = 320).

Perception of climate change risk	Total F(%)	Type of mining activity SSM F(%)	LSM F(%)
Aware of climate change			
Yes	309(96.6)	155(50.2)	154(49.8)
No	11(3.4)	6(54.5)	5(45.5)
Pearson Chi-Square: (χ^2(1)= 0.082, p= 0.775)			
Concerns about climate change risk effect			
Not at all concerned	74(23.1)	65(87.8)	9(12.2)
A little concerned	64(20.0)	30(46.9.4)	34(53.1)
Moderately concerned	119(37.2)	40(33.6)	79(66.4)
Very much concerned	63(19.7)	26(41.3)	37(58.7)
Pearson Chi-Square: (χ^2(3)= 57.320, p= .001, Cramer's V= 0.423)			
Signs and effect of climate change (n=572*)			
Increase in temperature and hot environment	259(45.3)	147(56.8)	112(43.2)
Irregular rainfall and storms	211(36.9)	137(64.9)	74(35.1)
Frequent floods	37(6.5)	23(62.2)	14(37.8)
Prolong drought	17(3.0)	9(52.9)	8(47.1)
Rising sea levels	37(6.5)	18(48.6)	19(51.4)
No response	11(1.9)	6(54.5)	5(45.5)
Pearson Chi-Square: (χ^2(5)= 84.977, p= 0.001, Cramer's V= 0.515)			
Mining workers at risk of workplace heat exposure due to climate change			
Yes	294(91.9)	148(50.3)	146(49.7)
No	26(8.1)	13(50.0)	13(50.0)
Pearson Chi-Square: (χ^2(1)= 0.001, p= 0.973)			
Environmental factors that influence risk of workplace heat exposure (n=542*)			
How hot the air is around the workplace	176(32.5)	112(63.6)	64(36.4)
The amount of air moisture in the outdoor settings or workplaces	43(7.9)	21(48.8)	22(51.2)
Air speed/movement around the workplace	94(17.3)	78(83.0)	16(17.0)
Heat radiation from the sun and other sources around the workplace	203(37.3)	120(59.1)	83(40.9)
No response	26(4.8)	13(50.0)	13(50.0)
Pearson Chi-Square: (χ^2(4)= 91.528, p= 0.001, Cramer's V= 0.535)			
Work-related factors that influence risk of workplace heat exposure (n=738)*			
Type of physical workload	167(22.6)	72(43.1)	95(56.9)
The duration of working hours	150(20.3)	108(72.0)	42(28.0)
Type of protective clothing, e.g. overall	67(9.1)	26(38.8)	41(61.2)
Access to the cooling system, e.g., air condition and fans	64(8.7)	37(57.8)	27(42.2)
Duration of break/rest hours	95(12.9)	77(81.1)	18(18.9)
Access to shade	82(11.1)	64(78.0)	18(22.0)
Access to drinking water	85(11.5)	71(83.5)	14(16.5)
Type of clothing	19(2.6)	9(47.4)	10(52.6)
No response	9(1.2)	6(66.3)	3(33.3)
Pearson Chi-Square: (χ^2(8)= 69.493, p= 0.001, Cramer's V= 0.466)			
Extent of concern about workplace heat exposure			
Not at all concerned	15(4.7)	11(73.3)	4(26.7)
Very little concerned	31(9.7)	14(45.2)	17(54.8)
Moderately concerned	53(16.6)	10(18.9)	43(81.1)
Very much concerned	221(69.0)	126(57.0)	95(43.0)
Pearson Chi-Square: (χ^2(3)= 28.441, p= 0.001, Cramer's V= 0.298)			

Source: Field survey, 2017

Table 4. Results of the difference in mining workers' experiences of occupational heat stress risks across the type of mining activity (Chi-Square test) (n = 320).

Experiences of occupational heat stress risks	Total F(%)	Type of mining activity SSM F(%)	LSM F(%)
Heat-related illness experience			
Yes	260(81.3)	133(51.2)	127(48.8)
No	60(18.8)	28(46.7)	32(53.3)
Pearson Chi-Square: (χ^2(1)= 0.393, p= 0.531)			
Type of heat-related illness experience (n=708*)			
Excessive sweating	178(25.1)	121(68.0)	57(32.0)
Headaches	146(20.6)	111(76.0)	35(24.0)
Heat exhaustion/tiredness	138(19.5)	98(71.0)	40(29.0)
Heat cramps (pains)	57(8.1)	25(43.9)	32(56.1)
Heat rash	101(14.3)	84(83.2)	17(16.8)
Heat syncope (fainting)	25(3.5)	20(80.0)	5(20.0)
Admitted to the hospital due to heat stroke	3(0.4)	2(66.7)	1(33.3)
No response	60(8.5)	29(48.3)	31(51.7)
Pearson Chi-Square: (χ^2(7)= 121.738, p= 0.001, Cramer's V= 0.617)			
Heat-related injury experience			
Yes	227(70.9)	119(52.4)	108(47.6)
No	93(29.1)	42(45.2)	51(54.8)
Pearson Chi-Square: (χ^2(1)= 1.392, p= 0.238)			
Extent of heat-related injury			
Minor	94(29.4)	30(31.9)	64(68.1)
moderate	58(18.1)	24(41.4)	34(58.6)
Serious	64(20.1)	59(92.2)	5(7.8)
Severe	6(1.9)	2(33.3)	4(66.7)
critical	5(1.6)	4(80.0)	1(20.0)
No response	93(29.1)	42(45.2)	51(54.8)
Pearson Chi-Square: (χ^2(5)= 62.912, p= 0.001, Cramer's V= 0.443)			
Type of heat-related injury experience (n=443)*			
Burns from the sun	41(9.3)	14(34.1)	27(65.9)
Burns from hot objects/surfaces	49(11.0)	21(42.9)	28(57.1)
Falls, trips, and slips due to dizziness, fainting and fatigue	52(11.7)	32(61.5)	20(38.5)
Loss of grip and controls due to sweaty hands	41(9.3)	24(58.5)	17(41.5)
Being hit by objects	86(19.4)	76(88.4)	10(11.6)
Hitting objects	81(18.3)	62(76.5)	19(23.5)
No response	93(21.0)	41(44.1)	52(55.9)
Pearson Chi-Square: (χ^2(6)= 81.215, p= 0.001, Cramer's V= 0.504)			
Heat-related injury witnessed			
Yes	265(82.8)	140(52.8)	125(47.2)
No	55(17.2)	21(38.2)	34(61.8)
Pearson Chi-Square: (χ^2(1)= 3.909, p= 0.048, *Phi*= 0.111)			
Type of heat-related injury experience (n=474)*			
Burns from the sun	39(8.2)	17(43.6)	22(56.4)
Burns from hot objects/surfaces	62(13.1)	22(35.5)	40(64.5)
Falls, trips, and slips due to dizziness, fainting and fatigue	86(18.1)	54(62.8)	32(37.2)
Loss of grip and controls due to sweaty hands	32(6.8)	21(65.6)	11(34.4)
Being hit by objects	104(21.9)	87(83.7)	17(16.3)
Hitting objects	95(20.0)	68(71.6)	27(28.4)
No response	56(11.8)	21(37.5)	35(62.5)
Pearson Chi-Square: (χ^2(6)= 85.223, p= 0.001, Cramer's V= 0.516)			

Source: Field survey, 2017

Figures 1 to 7

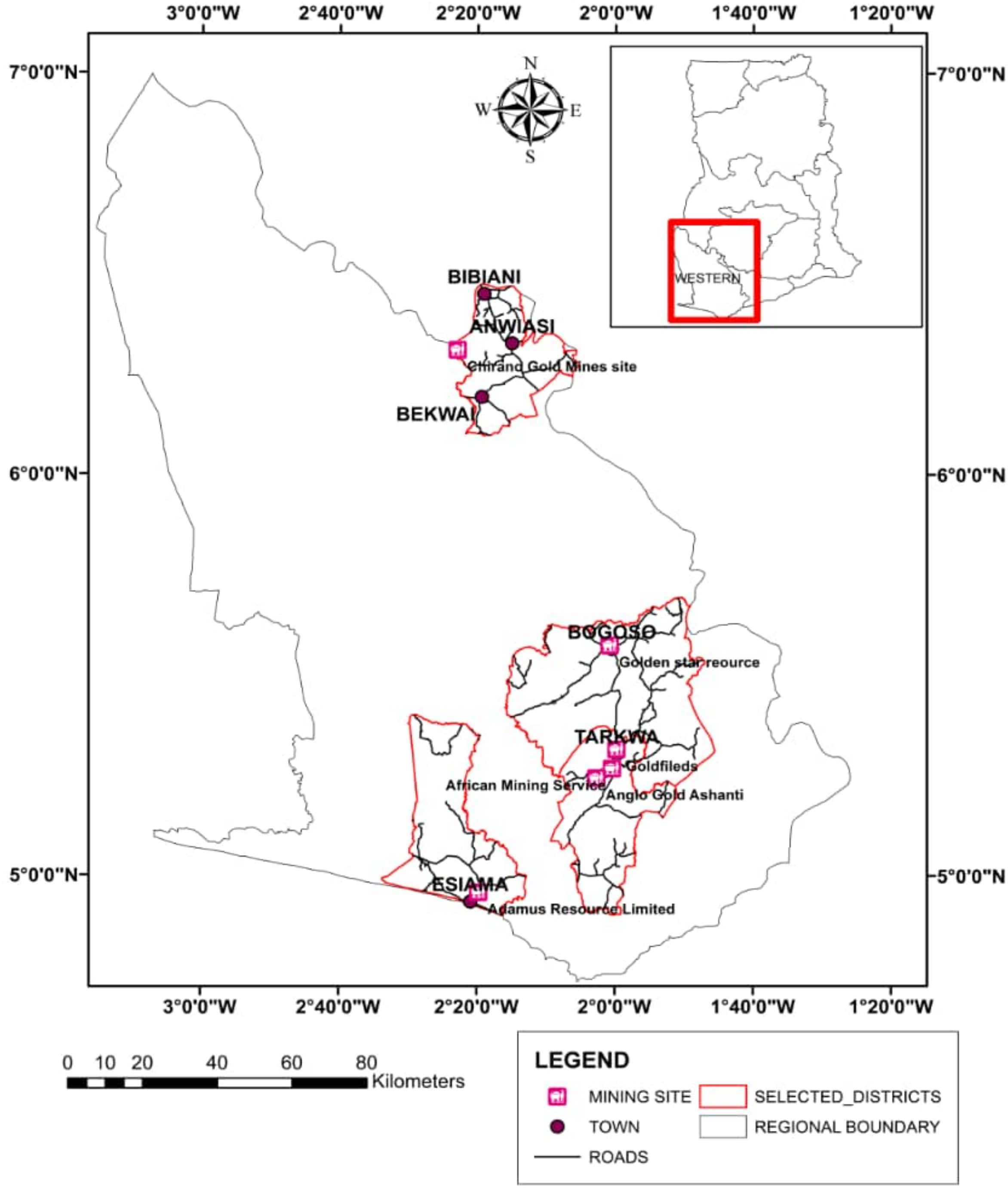


Fig 1. A map showing five mining sites located in the Western Region of Ghana

Source: Department of Geography and Regional Planning, University of Cape Coast, 2018

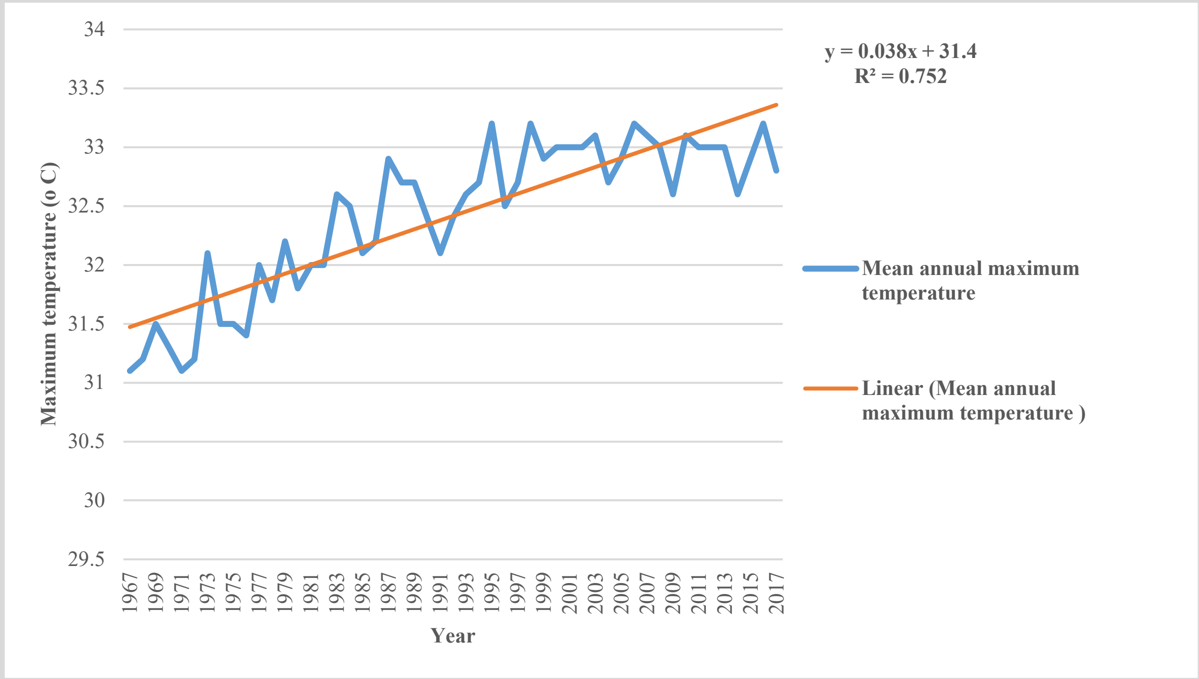


Fig 2 Trend and variations in mean maximum temperature of Western Region

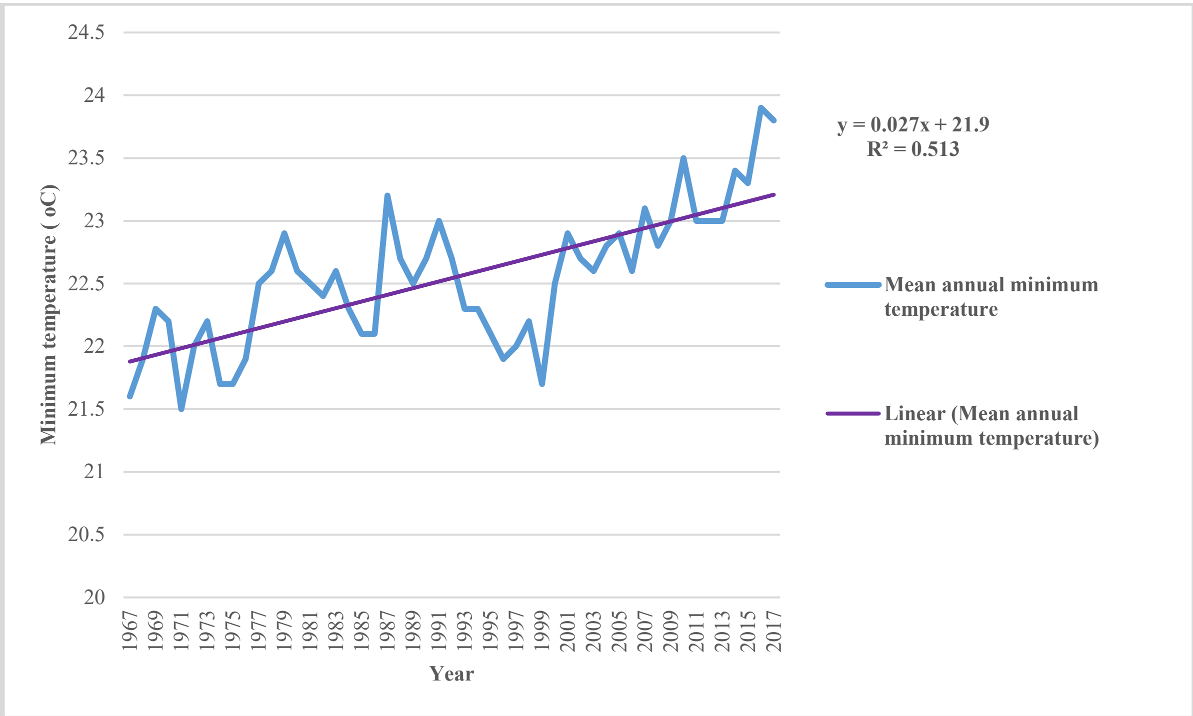


Fig 3 Trend and variations in mean minimum temperature of Western Region

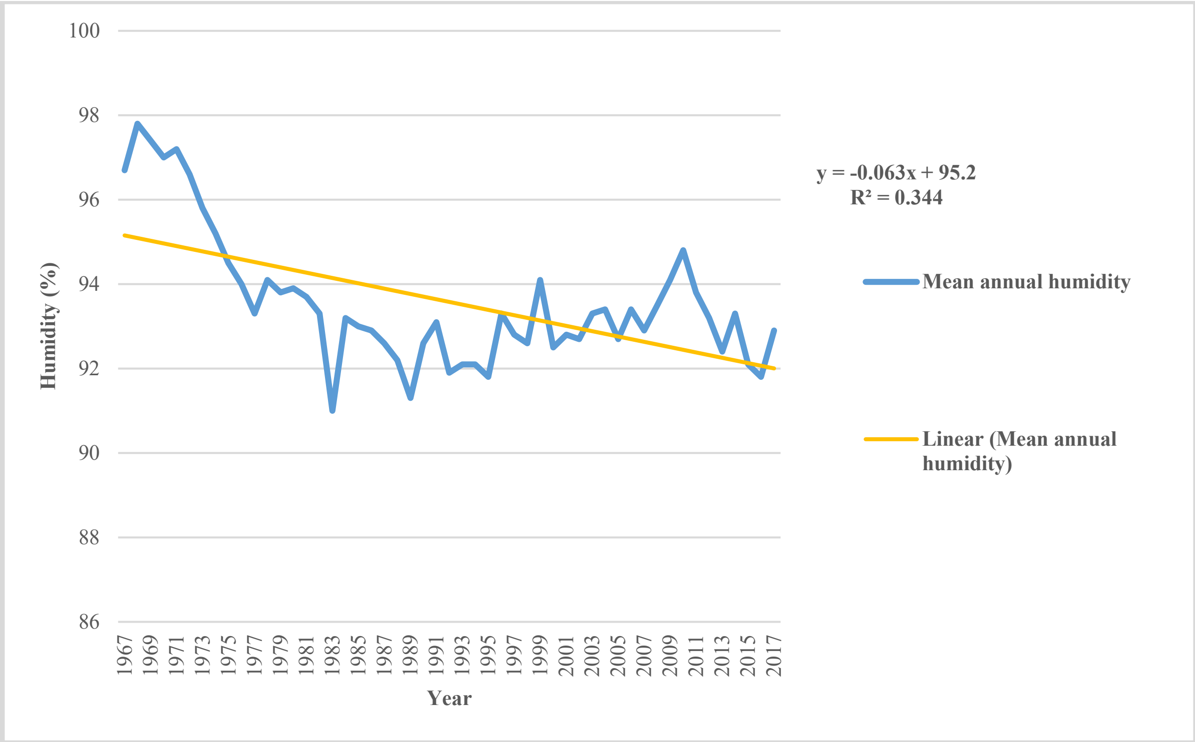


Fig 4 Trend and variations in mean annual humidity of Western Region

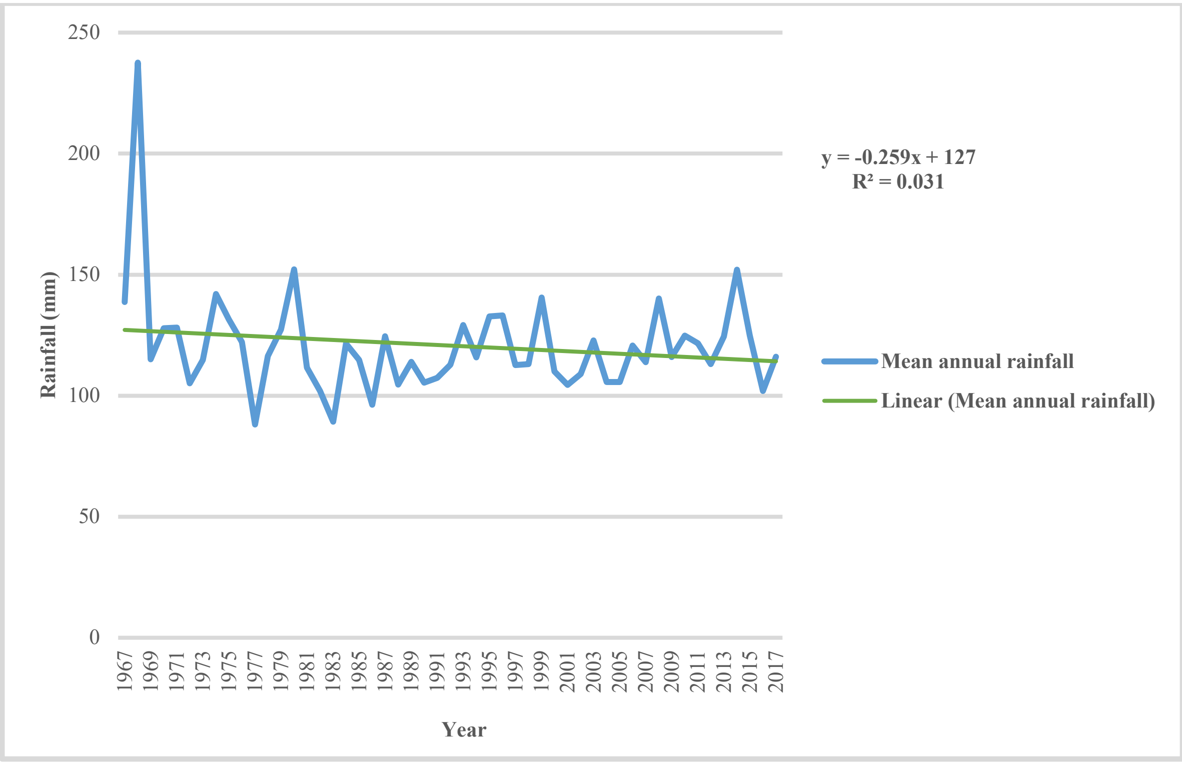
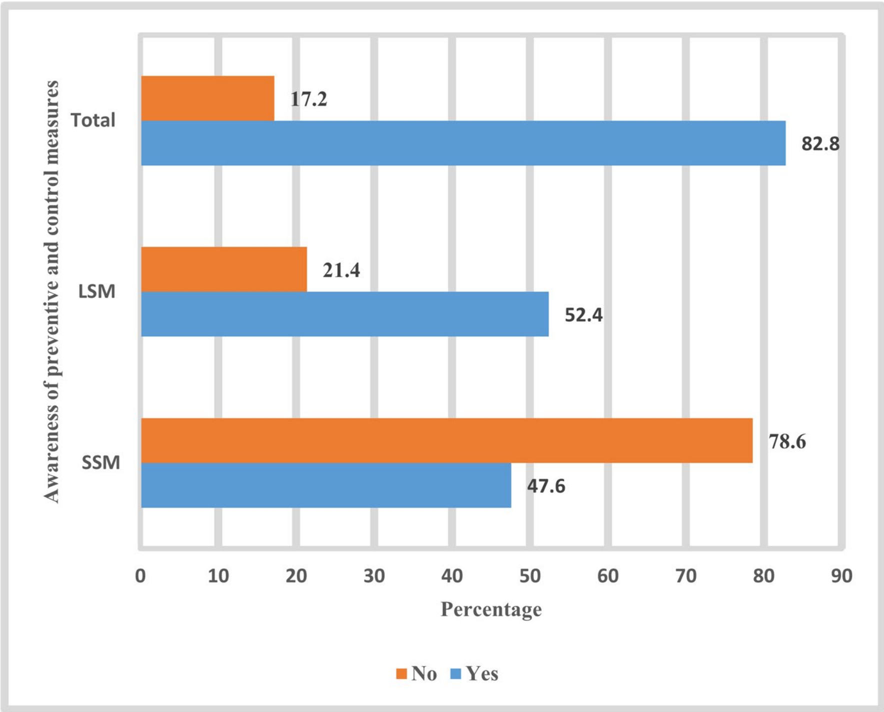


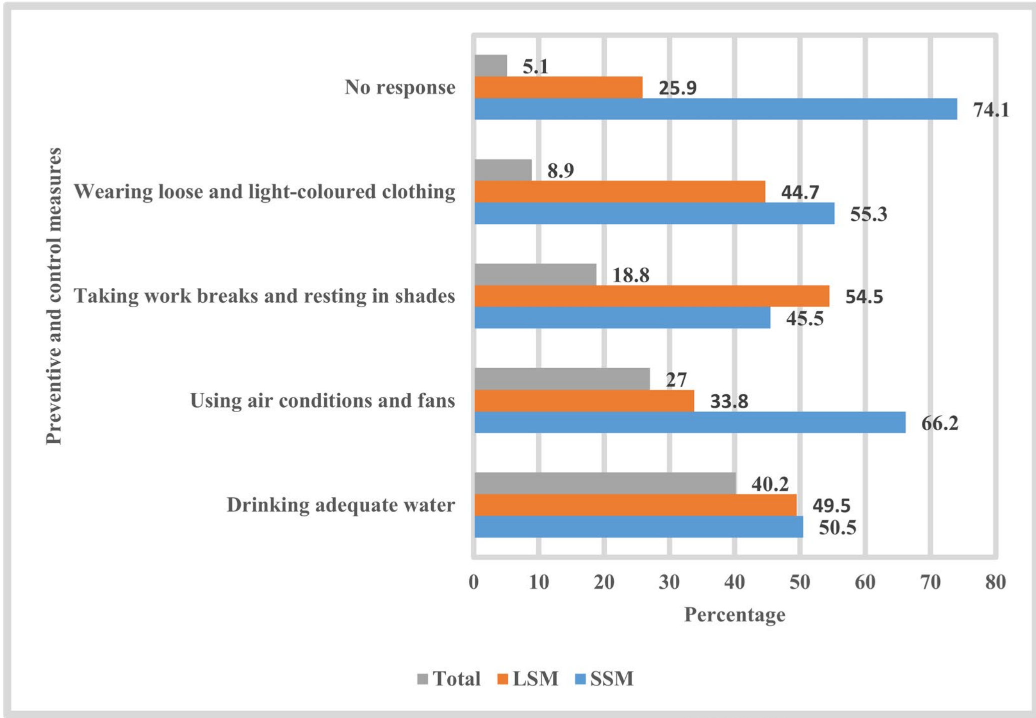
Fig 5 Trend and variations in mean annual rainfall of Western Region



n=320, Pearson Chi-Square: ($\chi^2(1) = 9.802$, $p= 0.002$, *Phi*= 0.175)

Fig 6. Results of the difference in mining workers' awareness of preventive and control measures of occupational heat stress due to climate change across the type of mining activity

Source: Field survey, 2017



n=527*, Pearson Chi-Square: ($\chi^2(4) = 51.853$, $p= 0.001$, Cramer's *V*= 0.403)

Fig 7. Results of the difference in mining workers' preventive and control measures of occupational heat stress due to climate change across the type of mining activity

Source: Field survey, 2017